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Impact of Large 132/33 kV Power Transformer on Distance Protection in Bangladesh

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***Abstract*—To meet the rapid load increasing in Bangladesh, the government incorporates large power transformers (132/33kV, 80/120MVA) to serve the demand. Due to their low equivalent impedance, it significantly impacts the distance relays zone reach settings, especially in zone-3. This paper presents the effect of large power transformer on zone-3 reach settings, protection zone overlaps, the adjoining long line outside of the protection zone, and their resulting consequences. This paper proposes a systematic approach for overcoming the distance relays zone setting reach problem, ensuring zone overlapping on distance protection relays for the adjoining long line, and incorporating large power transformers into distance protection zone with proper relay coordination. For simulation, the DIgSILENT PowerFactory 2021 software is used. The short-circuit calculation is performed using the IEC 60909 method. For illustrating impedance seen by the distance relay in different fault conditions and locations, the 7SA522 line distance relay of SIEMENS is utilized. Simulations results (R-X diagram) show the effectiveness of the proposed approach, which can save the transformer from firing and minimize its damages in Bangladesh.**

Keywords*—distance protection, zone-3, line protection, power grid company of Bangladesh Ltd., PGCB, large transformer impact, DIgSILENT PowerFactory.

I. Introduction

The power system of Bangladesh is expanding rapidly and getting complex day by day. The load of the grid substation is also increasing with time due to the government's hundred percentage electrification target. The government made power system master planning in 2010 and revised it in 2016 [1]. The maximum generation of Bangladesh significantly changed after 2009. In the year 2009-10, the maximum power generation was 4606 MW, and in the year 2018-19, the maximum power generation was 12,893 MW, as shown in Fig. 1 [2]. Due to the pandemic situation (Covid-19), the 2019-2020 generation was near about the same as 2018-2019. Due to the rapidly increasing demand, power evacuation from generation to distribution has become a challenge. A vast infrastructure needs to develop for power evacuation throughout the country. The government has already taken initiatives to establish the infrastructure. Many projects are ongoing at the generation, transmission, and distribution levels. Some projects are finished, and some projects will be completed soon. Due to the rapidly increasing demand, the power sector of Bangladesh passed through a transition period. To cope with the demand, the state-owned company, Power Grid Company of Bangladesh Ltd. (PGCB), responsible for power transmission in Bangladesh, takes new projects, upgrades line conductor, and 132/33kV power transformers. In most cases, the size of the power transformer is 80/120MVA, and in some cases, 50/75MVA is also used. These transformers greatly help to evacuate power.

The impedance of such a large 132/33kV transformer is low. It is crucial when two or more 120MVA transformers are operating in parallel. The equivalent impedance of the transformer becomes low, which significantly impacts zone-3 reach settings, and it arises protection coordination challenges to protection engineers.

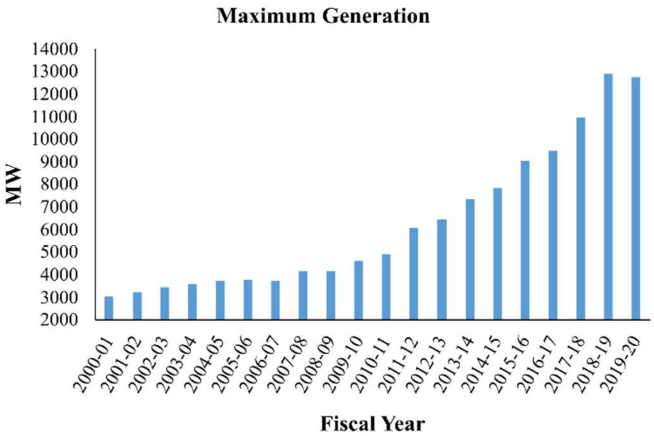

Fig. 1. Maximum generations in Bangladesh [2].

Fast clearance of fault is the key prerequisite at the transmission level network [3], where distance protection is widely used [4]. Distance relays are fast in operation and are more appropriate for primary protection schemes of transmission and sub-transmission lines. The distance relaying is based on the measurement of the short-circuit impedance, which is proportional to the distance to a fault [5]. Several protection zones can consider for relay settings to protect a transmission line. The distance protection zones of relays help to isolate faulty parts of the system and reduce damages. These protection zones are normally selected considering worst-case scenarios and factors that impact the performance of the relay [6]. The primary high-speed protection for a significant portion of the transmission line is provided by the Zone-1 of a distance relay [7],[8], whereas, Zone-2 covers the rest of the protected line and provides some backup for the remote end bus [9]. Generally, Zone-3 is to protect the remote end long line. Zone-2 and zone-3 are time-delayed protection. In protective relaying, the relay should only trip for a fault in its protective zone and not trip for a fault outside its protective zone, except relay or circuit breaker failure. Zone-2 or zone-3 removes the fault in the event of remote end feeder main protection or circuit breaker failure. Hence, determining the accurate zone-3 setting of distance relay is necessary. Zone-3 is recognized as one of the contributing causes of blackouts. Main transmission line tripping will result in loss of power to a major portion of the system and economic loss to both the supplier and the customer [10].

One of the crucial aspects of the protection schemes design is to confirm the proper coordination among various relays used in power systems. However, distance relays are also prevalent in transmission and sub-transmission systems due to their fast operation [11]. The measurement of the current and voltage, hence calculating the apparent impedance, is the distance relay's basic principle [12]. The distance relay calculates the impedance and compares it with its relay settings values. If the relay measured impedance is lower than the setting value, then it senses the fault. Based on the measured impedance, the distance relay declares the fault zone, starts the respective zone timer block, and gives a trip after the timer expired.

The general philosophy of the protection scheme has an overlapping zone (Fig. 2). The overlapping zone ensures backup protection for the remote end (Fig. 3). The relay in the substation **A** provides backup protection for the substation **B**. Similarly, the substation B gives backup protection to the substation **C**.

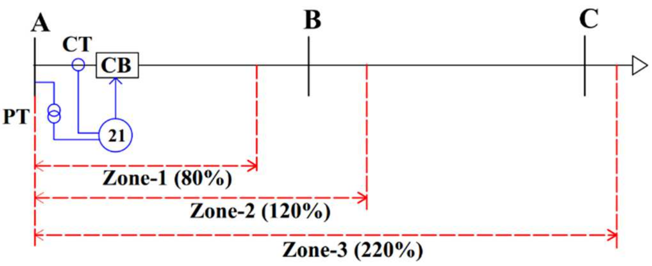

Fig. 2. Typical distance relay settings zones [13].

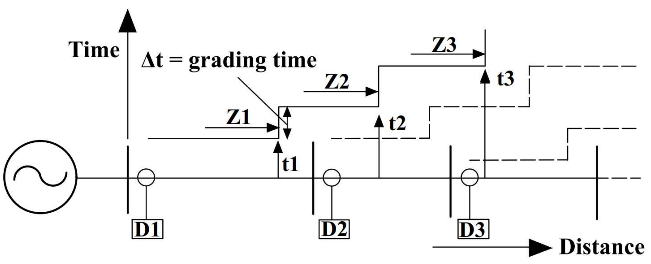

Fig. 3. Typical distance overlapping zones [14].

Large power transformer impacts on distance protection are not analyzed earlier in the available literature. Literature comparing the conventional distance protection zone settings and PGCB current practice are not available to the best of our knowledge. Therefore, this paper analyzes how the large power transformer affects the distance protection zone settings and compares the conventional distance settings technique and PGCB setting practice. This paper also analyzes how the zone overlapping is missed due to the large power transformers and their solution. Moreover, it analyzes PGCB's setting practice limitations, consequences, and how these limitations can be overcome. For interpreting the proposed methodology, the DIgSILENT PowerFactory 2021 software and for illustrating appeared impedance seen by the line relay in different fault conditions and fault locations, SIEMENS distance relay 7SA522 is utilized. The simulation results show how zone-3 can protect the adjoining long line and save the transformer from failure or significantly minimize the damages.

II. Settings Description

A. Conventional Distance Zone-3 Settings Philosophy

According to the conventional technique, zone-3 settings can be specified in two ways, as given below.

1) Scenario 1: Consider Fig. 4. The impedance should be seen by the relay located at the bus A is protected line impedance and adjoining long line impedance from the bus B [15].

Z3 = (Protected line + Adjoining long line) × Safety factor,

$$Z3 = k_1 \times (Z_{AB} + Z_{BC}), \quad (1)$$

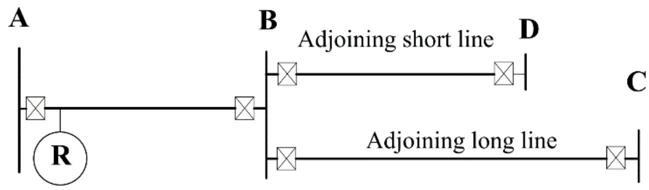

Fig. 4. Simple transmission network.

where Z3 is the zone-3 settings of relay R in line AB, k1 is a security factor within the range of 1.10 to 1.20, ZAB is the positive sequence impedance of the protected line A-B, and ZBC is the positive sequence impedance of the next line BC.

2) Scenario 2: The distance zone-3 reach should be as high as possible, but it should not overlap with the next protective relays on the lines emanating from the remote bus B [3].

$$Z3 = k2 \times (ZAB + \text{short adjoining line}), \quad (2)$$

where k2 is a safety factor, normally k2 = within the range of 0.80 to 0.90.

B. PGCB Distance Settings Philosophy

PGCB zone-3 settings guidelines are given below [16]. For zone-3 distance relay settings, the lowest value among the following three impedances should consider as current practice in PGCB:

1) 200% of protected line impedance.

2) 100% of protected line impedance + 100% impedance of the longest adjoining line of the remote substation.

3) 100% of the protected line impedance + 50% impedance of the largest transformer[1] connected in a remote substation.

In conventional philosophy, the scenario 1 provides more zone-3 reach than the scenario 2. Therefore, this paper will focus on the scenario 1 only.

[1] Equivalent impedance of transformers connected in parallel.

III. SETTINGS COMPARISON AND CONSEQUENCES

Consider a substation **A** has a 50 km line (protected line) and feeds to a substation **B** (remote substation) (Fig. 5) having two 132/33kV 120 MVA transformers operating in parallel (percentage impedance of 12%). From the remote end substation, there is another 50 km long line (adjoining) to the substation **C**. Consider both protected and adjoining long lines have a reactance of 0.389 Ω/km. The protected line distance relay is **R,** and zone settings for **R** according to the conventional and PGCB practice are given below.

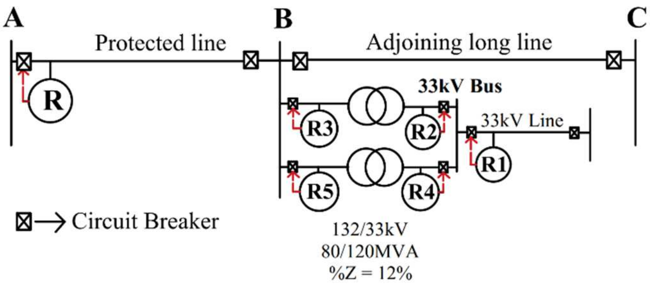

Fig. 5. Considered substation.

- Conventional method (as per scenario 1):

Zone-1 = 80% of line = 0.80 × 50 × 0.389 Ω = 15.56 Ω
Zone-2 = 120% line = 23.34 Ω
Zone-3 = 1.20 × (100% line + 100% of adjoining long line) = 46.68 Ω

- PGCB practice:

Zone-1 = 80% of line = 15.56 Ω
Zone-2 = 100% line + 30% impedance of paralleled transformer = 22.06 Ω
Zone-3 = 100% line + 50% impedance of paralleled transformer = 23.805 Ω

An impedance (R-X) diagram is an essential tool for the protection engineer for analyzing the behavior of distance protection relays. The relay characteristic, short-circuit impedance, and sometimes the measured load impedance is represented in the complex R-X plane [14]. The R-X diagrams for the above settings with the conventional method (adjoining long line) and PGCB practice are shown in Fig. 6 and Fig. 7, respectively. From these diagrams, it can be seen that there is a difference in zone-3 settings between the conventional method and PGCB practice.

As described earlier, the zone overlapping is vital in case of DC failure or primary protection failure. As per the PGCB settings, the philosophy of adjoining full line protection may not be possible (Fig. 8). From Fig. 8, zone-3 only covers the 11.18 km line (red dashed) from the substation **B** in the forward direction when two 80/120MVA transformers operate in parallel. As the line length is 50 km, the rest of the 38.82 km line has no overlapping distance protection zone. Therefore, if any fault occurs (after the 11.18km line) and protective relay, circuit breaker, or DC fails in the substation **B,** then no overlapping zone is available from the substation **A**. As a result, the fault will clear by overcurrent earth fault protection from the substation **A**, which is much slower than the distance relay. In PGCB settings practice, the zone-3 reach is significantly reduced due to the large power transformer. For these, zone-3 cannot provide backup distance protection for the next adjoining lines.

If zone-3 is large, then zone-3 impedance may include some part of the 33kV distribution line also. However, if the distribution feeder relay and the transformer protection relay are correctly coordinated, then, in the case of a 33kV feeder fault, the R1 relay will give trips to the 33kV feeder circuit breaker (Fig. 5). A 33kV feeder protection is coordinated with 33kV and 132kV transformer protection. In case of 33kV bus fault or 33kV feeder circuit breaker failure, the R2 and R4 relay will give a trip to 33kV transformer incomer circuit breakers. If both 33kV side transformer incomer circuit breaker fails to trip, then 132kV transformer side relays (R3 and R5) will operate. Thus, there is no chance to operate line protection relay (R) before transformer protection relays. If the DC failure occurred in the substation, no protection of the transformer could trip the circuit breaker, then the 132kV line distance relay (zone-3 protection) will operate. In these cases, distance relays can significantly reduce the tripping time and potential damages of the equipment.

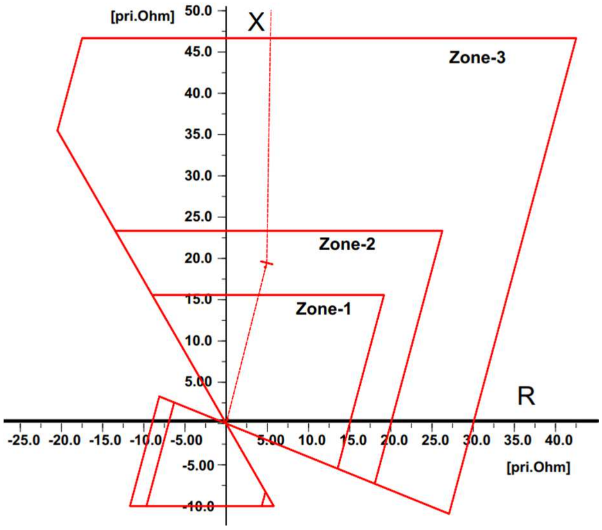

Fig. 6. Impedance (R-X) diagram with considering conventional method.

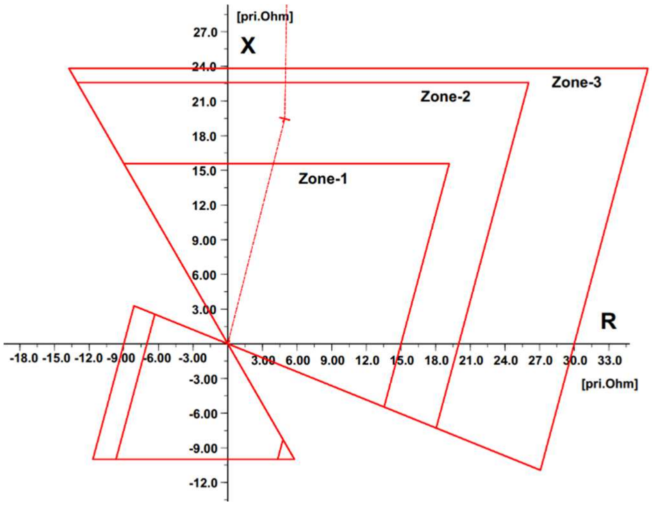

Fig. 7. Impedance (R-X) diagram with considering PGCB practice.

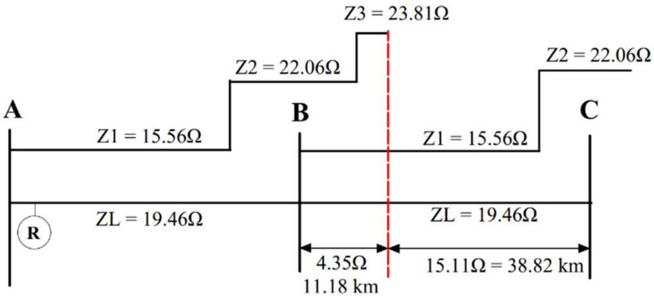

Fig. 8. Zone-3 with considering PGCB practice.

Fig. 9. 120MVA 132/33kV transformer failure in Kushtia substation.

Fig. 10. Kushtia transformer post-CT burst due to transformer fire.

In Kushtia and Mymensingh grid substation, 132/33kV 80/120 MVA transformer (Fig. 9) was burned [17],[18]. The DC failure occurred in the Kushtia 132/33kV substation, and the fault was in the 33kV bus. The fault was finally isolated after the transformer side 132kV post-CT was blasted (Fig.10) due to transformer fire and distance zone-2 operated at the remote end. From the CCTV footage, it was found that the fault was persisted for a reasonably long time. Kushtia substation received power from Bheramara 230/132kV substation. In the Kushtia end, the 132kV long line is 44 km towards the Jhenaidah substation. If this long line was inside the zone-3 reach of the Bheramara-Kushtia line distance protection, the fault could not persist a long time. It cleared in zone-3 tripping time, i.e., within 800ms. That could significantly reduce the transformer damage even can save the transformer.

This is one of the leading causes of increasing the damage of failure transformer. Power transformers are designed and built to withstand maximum through fault current around 1.00-2.00 seconds. If the transformer is possible to isolate from the grid before the designed time, then it is possible to save the transformer or significantly reduce the damage of the transformer for persisting external fault. Which will ensure a quick recovery of power systems and significantly reduce damages and outages.

IV. Proposed Methodology

This paper shows how to select suitable zone-3 reach settings by maintaining proper relay coordination. The methodology intends to select the maximum possible zone-3 reach settings by considering adjoining long line and remote end power transformers. Selecting the proper zone-3 impedance considering large power transformers is described in the flowchart (Fig. 11) and involves the following steps:

Step 1: Construct the system model in DIgSILENT PowerFactory 2021.

Step 2: Select zone-3 impedance = 100% of protected line plus next adjoining long line with security factor (k).

Step 3: Simulate 3-phase fault at 33kV bus and compare the relay impedance with the impedance in step 2.

Step 4: If the measured impedance by distance relay is less than step 2, go to step 5. If the measured impedance is more the step 2, then check the relay coordination at 33kV level is possible or not (R1 with R2/R4 by considering the fault current of the 33kV feeder and transformer). If coordination is possible, then set zone-3 = distance relay appeared impedance in 33kV bus fault. If not, then select zone-3 = step 2 impedance.

Step 5: Similarly, perform the simulation for phase-to-ground fault.

Step 6: Simulate the fault considering the transformers are operating in parallel and separate conditions.

Step 7: Simulate until the suitable impedance is achieved where 33kV side relay coordination has no issue and select the zone-3 impedance.

The system model in DIgSILENT PowerFactory 2021 considering Fig. 5, described in section III, is shown in Fig. 12.

V. Result and Discussion

The proposed methodology ensures the protection of the next adjoining long line. Using the flowchart and considering Fig. 5, zone-3 impedance 46.68 Ω can be achieved (assume k=1.20). For simulation and illustration, this paper is used DIgSILENT PowerFactory 2021 and SIEMENS line distance relay 7SA522. The methodology's effectiveness is verified by comparing the impedance diagram between PGCB settings and proposed settings in three different fault conditions. Here, the line's CT ratio is considered 1200/1A and the PT ratio 132000V/110V.

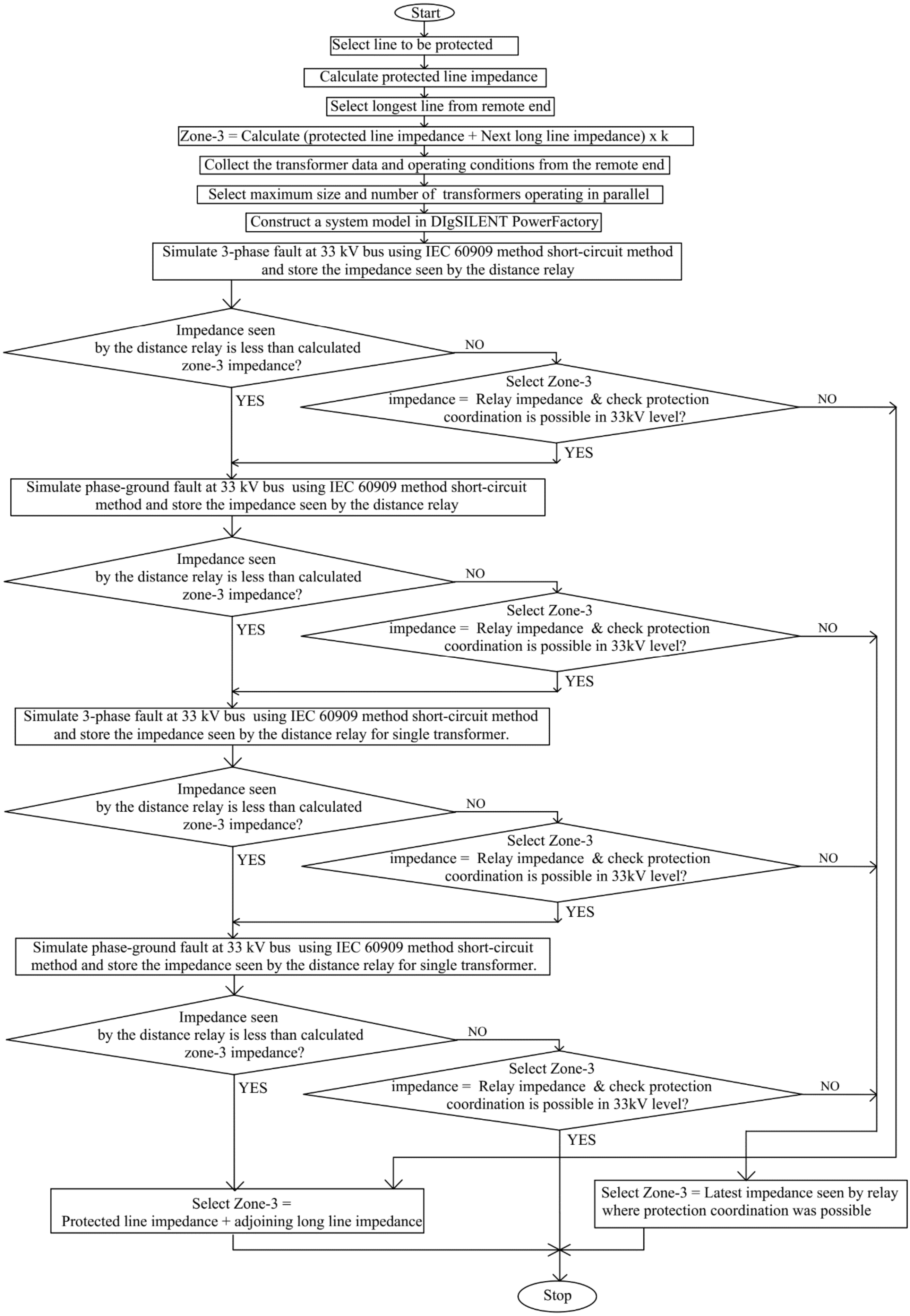

Fig. 11. Flowchart of selecting proper zone-3 settings.

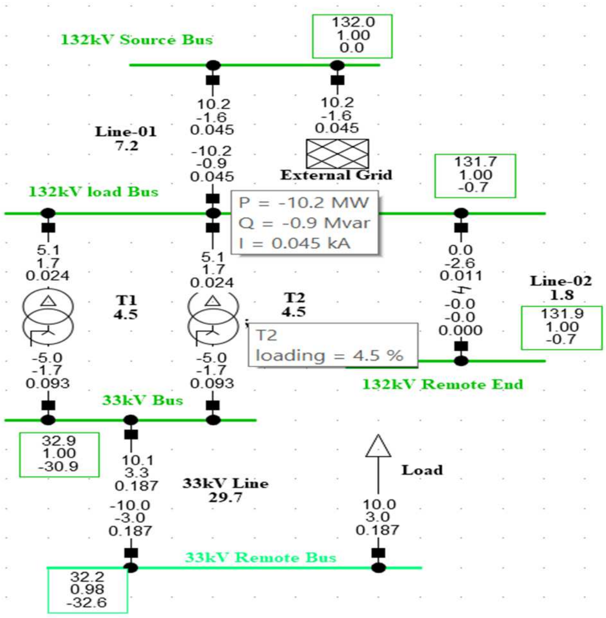

Fig. 12. System model in DIgSILENT PowerFactory.

Fault event 1: 3ph Fault at 100% of next adjoining long line at 132kV remote substation (200% of line). The fault is simulated at 132kV remote end substation in Fig. 12.

Impedance diagram shows that at 100 % of the next long line the fault is outside of zone-3 (Fig. 13) according to PGCB settings, whereas in the proposed methodology, fault impedance is inside the impedance diagram and gives tripping at zone-3 (Fig. 14) timing (600ms).

Fault event 2: Simulation of fault at 33kV bus. The fault is simulated at 33kV bus of Fig. 12.

A 3-phase fault is simulated at 33kV busbar. Impedance diagram shows that in the case of 33kV bus fault, according to PGCB settings philosophy, it is outside of zone-3 protection (Fig. 15), and according to the proposed methodology, the fault impedance is inside zone-3 (Fig.16) and gives trip at zone-3 timing.

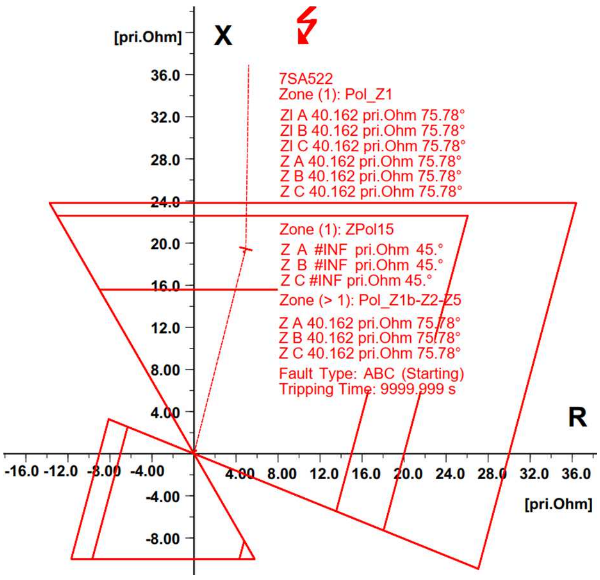

Fig. 13. Impedance (R-X) diagram at 100% of adjoining long line with PGCB settings.

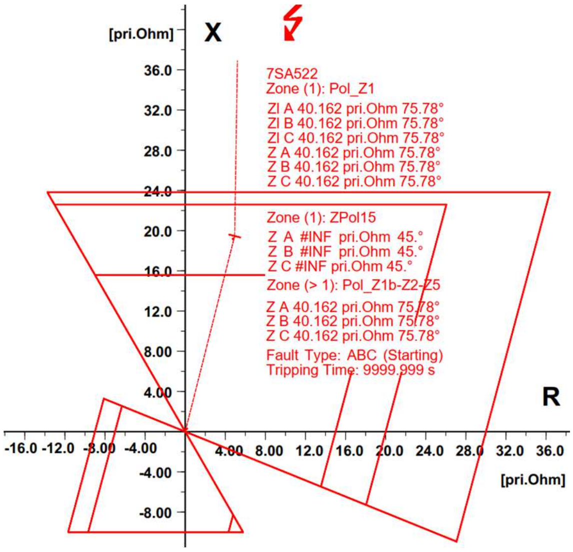

Fig. 14. Impedance (R-X) diagram at 100% of adjoining long line with the proposed approach.

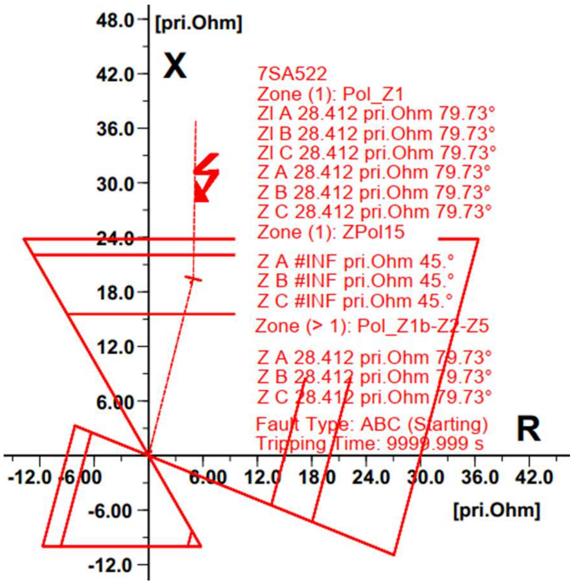

Fig. 15. Impedance (R-X) diagram at 33kV bus with PGCB settings.

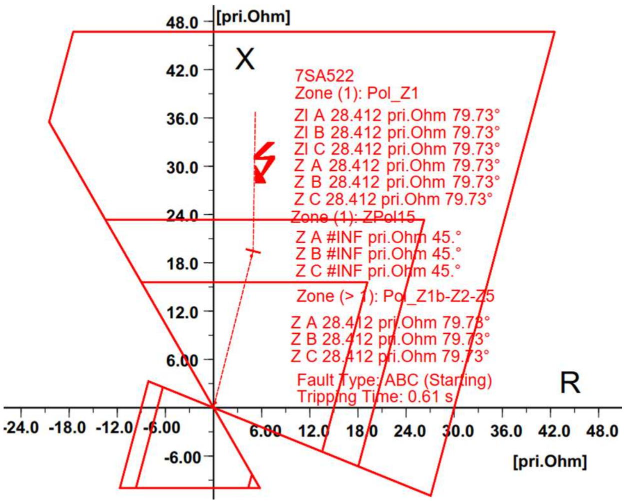

Fig. 16. Impedance (R-X) diagram at 33kV bus with the proposed approach.

Fault event 3: Fault at 33kV bus when two lines are feeding (Fig. 17).

A 3-phase and 1ph-earth, both faults are simulated when two lines are in service from the source end. According to the PGCB settings philosophy, the impedance diagram shows that the fault impedance is outside of zone-3 (Fig.18); hence no tripping, and according to the proposed methodology, fault impedance is inside zone-3 (Fig. 19 and Fig. 20) tripping zone. That ensures backup protection in case of DC or circuit breaker failure. The proposed methodology has a faster fault clearing time than the PGCB settings philosophy and ensures zone overlapping.

If the substation has adjoining long lines short in length, zone-3 can only protect the adjoining long line but not 33kV bus faults. This problem can solve by considering the appeared impedance in distance relay for 33kV bus fault equal to zone-3 impedance, which can give backup protection for the transformer. During this consideration, zone-3 impedance may overlap with the remote end feeders' zone-3 impedance. In this condition, zone-3 tripping time needs to be graded with remote end feeders.

If the remote end adjoining the long line is very long, then the 33kV distribution line will come inside the zone-3 protection zone. That can cause relay coordination problems. To solve this problem, simulate the fault at the end of the next long line and record the appeared impedance seen by the distance relay. Then, simulate the fault at 33kV bus and gradually increase it towards the 33kV distribution line, record the relay appeared impedance. Simulate up to relay appeared impedance equal to impedance seen at the end of 132kV adjoining long line, and record the 33kV line length where impedance matched. Then simulate phase-phase fault, phase-earth fault at that 33kV line length and find out the feeder fault current, transformer 33kV current contribution. Using this fault current, coordinate the relay of 33kV feeder, 33kV transformer incomer, and 132kV transformer incomer with zone-3. That secure relay coordination problem and selective tripping.

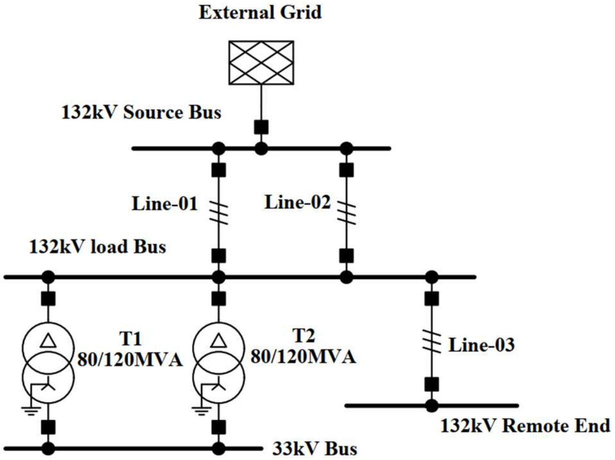

Fig. 17. Simulation of 33kV 3ph bus fault when both source lines (line-01 and line-02) are feeding.

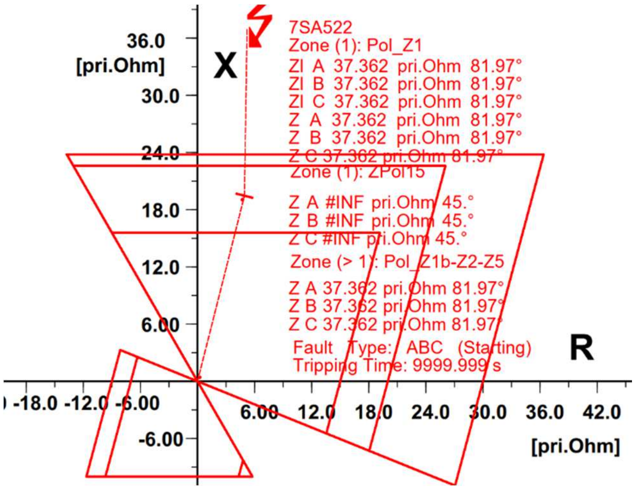

Fig. 18. Impedance (R-X) diagram at 33kV bus for 3ph fault with PGCB settings.

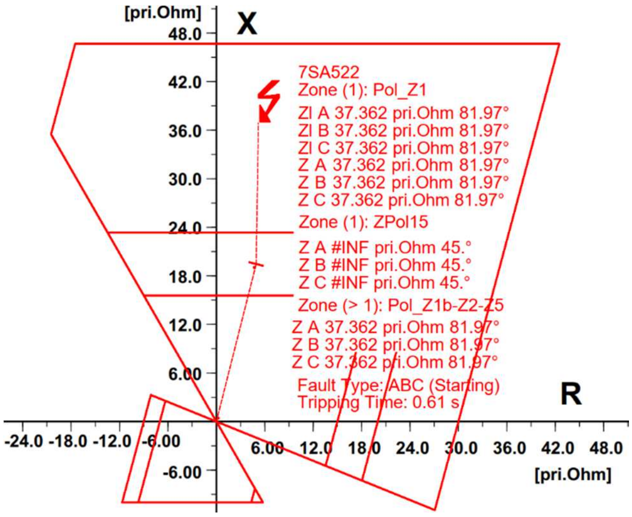

Fig. 19. Impedance (R-X) diagram at 33kV for 3ph bus with the proposed approach.

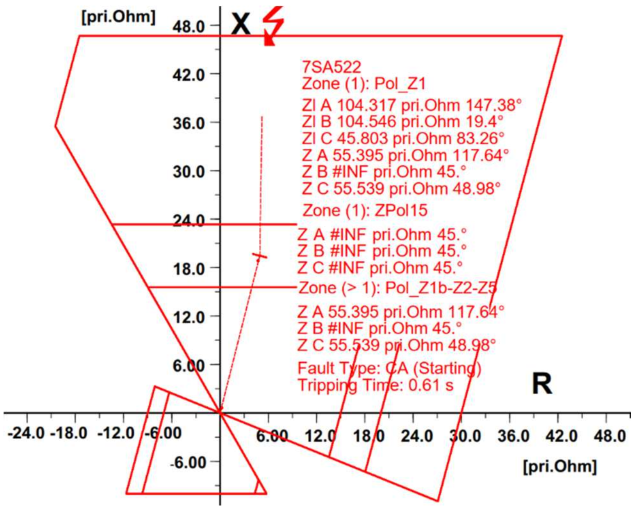

Fig. 20. Impedance (R-X) diagram for 1ph fault at 33kV bus with the proposed approach.

Some situations may arise depending on the power systems.

- Weak in feed: As a source local end substation is weak.

- Multiple infeed: If the remote end substation has numerous 132kV lines at the remote end, i.e., multiple in feeds

In the above situations, zone-3 will operate with a bit of delay. Zone-3 will operate after tripping of other strong in feeds. The proposed methodology can be applied in most of the 132kV lines for distance relay settings because of their length [19] and the power transformer size [20] in Bangladesh.

TABLE I. IMPEDANCE SEEN BY DISTANCE RELAY AT DIFFERENT OPERATING CONDITION OF TRANSFORMER.

	Fault at 33kV Bus			
Transformer Operating condition	**Parallel**	**Parallel**	**Single**	**Single**
Fault Type	3ph	1ph	3ph	1ph
Impedance seen by the relay (R) for 80/120MVA (Ohm)	8.49	12.74	16.98	25.47
Equivalent 132kV line (km)	21.83	32.75	43.13	65.48
Impedance seen by the relay (R) for 50/75 MVA (Ohm)	13.59	20.38	27.17	40.76
Equivalent 132kV line (km)	34.94	52.39	69.84	104.7

Transformer equivalent impedance seen by the distance relay and their equivalent length of 132kV line distance at different operating conditions is shown in Table I. These results are achieved from short circuit analysis using DIgSILENT PowerFactory 2021, and equivalent 132kV line is calculated using typical 132kV line reactance (0.389 Ω/km). Table I shows that when two 120MVA transformers operate in parallel, it acts as 21.83km 132kV line and 34.94km for two 75MVA transformers. Using Table I, it can easily understand what length of the next adjoining long line can be protected by distance relay without transformer relay coordination problem.

VI. CONCLUSION

Large power transformers are greatly impacted on distance relay zone reaches. The zone-3 reach of the PGCB method is conservative, which does not cover the next long line in most cases. Therefore, if the proposed philosophy can be adapted in distance protection, it will provide backup protection for the adjoining long line and transformers. The effectiveness of the proposed methodology is shown by quadrilateral impedance diagram of SIEMENS line distance relay (7SA522) using the DIgSILENT PowerFactory 2021 software at different fault conditions at 132kV and 33kV voltage levels. This paper illustrated how distance zone overlapping was missing due to the PGCB settings philosophy and how the proposed methodology effectively ensures the zone overlapping and secures the tripping with maintaining proper relay coordination at 33kV and 132kV voltage levels. This paper also explains the leading cause of the increasing damages of failure transformers in Kushtia and Mymensingh and how damages can be minimized. It is revealed that the proposed methodology can provide fast fault clearing time in case of the circuit breaker or DC failure with proper selectivity, which will significantly reduce the damage of equipment and quick restoration of power systems. In the future, the research will extend for formula estimation of critical length at 33kV level where 33kV and 132kV relays need to coordinate for different transformer conditions and formulating chart for critical 33kV length in Bangladesh perspective.

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